Issued January 17, 1917.

HAWAII AGRICULTURAL EXPERIMENT STATION,
J. M. WESTGATE, Agronomist in Charge.

Bulletin No. 42

COMPOSITION OF HAWAIIAN SOIL PARTICLES.

BY

WM. T. McGEORGE,
Former Chemist, Hawaii Agricultural Experiment Station.

UNDER THE SUPERVISION OF
STATES RELATIONS SERVICE,
Office of Experiment Stations,
U. S. DEPARTMENT OF AGRICULTURE.

WASHINGTON:
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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. True, Director of the States Relations Service, United States Department of Agriculture.]

E. W. Allen, *Chief of Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

Hawaii Agricultural Experiment Station.
Honolulu, Hawaii, December 14, 1915.

Sir: I have the honor to submit herewith, and recommend for publication as Bulletin No. 42 of the Hawaii Agricultural Experiment Station, a manuscript entitled "The Composition of Hawaiian Soil Particles," by Wm. T. McGeorge, formerly chemist of this station. The variations in Hawaiian soils as compared with the soils of the mainland of the United States are so great and unusual as to make it of economic importance to determine as many as possible of the fundamental causes of the variations. As pointed out in the accompanying manuscript, the size of the particles of different Hawaiian soils bears a distinct relation to their composition.

Respectfully,

J. M. Westgate,
Agronomist in Charge.

Dr. A. C. True,
Director States Relations Service,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. True, *Director.*

Publication authorized.
D. F. Houston, *Secretary of Agriculture.*

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[1] Appointed July 25, 1915, to succeed Wm. T. McGeorge, transferred to U. S. Department of Agriculture, Bureau of Chemistry.

COMPOSITION OF HAWAIIAN SOIL PARTICLES.

CONTENTS.

INTRODUCTION.

One of the primary characteristics of Hawaiian soils is the wide diversity of types which makes difficult their classification according to the usual methods employed in soil surveys. A wide variation in chemical composition, as well as in physical properties, is found within very short distances. During a recent investigation in this laboratory upon the determination of humus, the character of the clay in Hawaiian soils, as regards certain of its properties, was found to be radically different from that in mainland soils. Chief among these abnormal properties is the incomplete coagulation when coagulants are added. This is especially true in case of addition of ammonium carbonate, which has been successfully used on mainland soils for the coagulation of clay in humus extracts.

This peculiarity of the clay has led to a study of the composition of the coagulable and noncoagulable grains and a further investigation upon the composition of the clay, fine silt, silt, fine sand, and coarse sand separates in the important Hawaiian types of soil differing in color, chemical composition, and physical properties.

ORIGIN OF HAWAIIAN SOILS.

In order to understand clearly the composition of the soil separates, it is necessary to know something of the origin of Hawaiian soils, at least the three possible sources from which they may be derived, namely, volcanic lava, volcanic ash, and coral sand. As, with the exception of small areas near the sea, coral sand need not be considered as a factor in soil formation in the islands, and as there is little material difference in the composition of the lava and ash, the source of Hawaiian soils narrows down to volcanic basalts of a more or less uniform composition. Analyses of lava, volcanic ash, and coral sand are given in the following table:

Analyses of lava, volcanic ash, and coral sand.

Constituents.	Lava.						
	From Oahu.				From Hawaii.		
	Sample A.	Sample B.	Sample E.	Sample F.	Sample No. 501.	Sample No. 502.	Sample No. 503.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Silica (SiO_2)	52.45	52.15	51.98	52.24	48.88	48.55	52.07
Alumina (Al_2O_3)	11.49	12.57	15.85	16.00	12.84	14.83	14.12
Ferric oxid (Fe_2O_3)	3.66	3.36	2.90	3.73	.30	2.44	2.64
Ferrous oxid (FeO)	6.90	7.07	6.84	5.89	8.52	6.07	7.01
Manganese oxid (Mn_3O_4)	.36	.50	.92	.68	.31	.66	.72
Lime (CaO)	10.32	8.54	9.57	9.54	9.55	8.56	10.71
Magnesia (MgO)	5.81	6.51	5.61	5.90	10.29	14.22	7.51
Potash (K_2O)	.89	.84	.97	.86	.75	.72	.74
Soda (Na_2O)	2.44	2.64	2.70	2.65	1.44	1.56	1.93
Sulphur trioxid (SO_3)	.20	.61	.51	.53	.33	.19	.35
Phosphorus pentoxid (P_2O_5)	.38	.28	.22	.11	.21	.22	.24
Titanic oxid (TiO_2)	4.07	4.07	1.50	1.50	2.54	2.15	2.42
Moisture	1.02	.94	1.04	.54	4.45	.09	0

Constituents.	Lava.			Volcanic ash.			Coral sand.
	From Hawaii.			From Maui.		From Oahu.	From Oahu.
	Sample No. 504.	Sample No. 505.	Sample No. 519.	Sample No. 506.	Sample No. 507.	Sample No. 132.	Sample No. 227.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Silica (SiO_2)	51.25	49.94	50.69	45.54	46.98	36.82	2.60
Alumina (Al_2O_3)	14.36	14.42	15.62	17.42	16.62	18.08	0
Ferric oxid (Fe_2O_3)	3.30	1.04	.49	8.60	7.08	10.40	.21
Ferrous oxid (FeO)	6.43	8.01	4.65	....	....	4.32	....
Manganese oxid (Mn_2O_4)	.44	.20	.28	1.17	.18	.46	0
Lime (CaO)	10.65	11.59	11.14	8.90	7.16	9.52	92.40
Magnesia (MgO)	9.12	9.08	6.55	6.14	5.58	.54	2.90
Potash (K_2O)	.64	.80	.90	1.82	1.32	5.62	.31
Soda (Na_2O)	1.96	1.79	2.56	2.92	2.62	10.20	.46
Sulphur trioxid (SO_3)	.33	.33	.78	.36	.46	.18	.55
Phosphorus pentoxid (P_2O_5)	.17	.26	.34	.63	.59	.70	.21
Titanic oxid (TiO_2)	2.35	2.86	5.53	6.00	6.60	5.50	0
Moisture	0	0	.10	.74	1.55	.09	.36

Samples A, B, E, and F are from unaltered lava in the Wahiawa district of Oahu. Nos. 501 to 505, inclusive, are from the different flows of Mauna Loa on the Island of Hawaii. No. 501 was taken from the flow of 1823 and had undergone a slight decomposition; No. 502 was taken from the flow of 1868 and showed slight changes in appearance, due probably to hydration and leaching; No. 503 came from the flow of 1883; No. 504 from that of 1907; and No. 505 from the small overflow of 1910 at Kilauea. No. 519 is a sample of "Pele's Hair," a term that is used to describe the hair-like threads of lava formed at Kilauea by explosions in the molten lava. Nos. 506 and 507 are black ash from Haleakala Crater on Maui, while No. 132 is a sample of black ash from Oahu which had been submerged at one time by the sea. No. 227 is a sample of coral sand from the island of Oahu. There is a marked similarity in the composition of the lavas from both islands. A slight variation in the content of soda and magnesia is the only perceptible difference. The same is also true of the volcanic ash from different sources, except that potash should be included as one of the variable constituents. The coral sand contains 92.4 per cent of carbonate of lime. The important silicates occurring in the lavas include the pyroxenes, amphiboles, and soda-lime feldspars, while the ash contains more or less magnetic iron oxid.

The primary agent of disintegration in Hawaii is weathering. However, the climatic factors influencing decomposition vary so widely even in adjacent districts that the soils formed are far from uniform in composition or properties. Rainfall varies from a fraction of an inch to over 200 inches per annum, hence there are humid, dry, and even arid districts. Temperature changes, while not rapid, vary from the tropical heat to temperate conditions, with snow at times in the higher mountains. Again there must be included as an agent of disintegration the trade winds which play no small part in the transportation of soil grains. The process of lava disintegration is generally referred to as laterisation, but in certain of the districts submersion by the sea following their formation has materially influenced the disintegration of the laterite and the composition of the soil.

Since practically all the known weathering agents are concerned in the formation of Hawaiian soils, acting either separately or in different combinations, it is not surprising that the types vary so greatly in closely situated districts.

CHANGES DURING DISINTEGRATION.

In a previous publication of this station[1] analyses are given showing the effects of disintegration on the composition of lava during the process of soil formation. These analyses are reproduced here in order to show more clearly the relation between the composition of the soil particles and the original lava.

[1] Hawaii Sta. Bul. 26 (1912).

Analyses of lava and adjacent lava disintegration products.

Constituents.	A. Lava.	C. Disintegration products.	B. Lava.	D. Disintegration products.	E. Lava.	G. Disintegration products.	F. Lava.	H. Disintegration products.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Silica (SiO_2)	52.45	20.29	52.15	24.01	51.98	26.82	52.24	32.00
Alumina (Al_2O_3)	11.49	37.97	12.57	36.27	15.85	30.13	16.00	35.28
Ferric oxid (Fe_2O_3)	3.66	15.01	3.36	14.29	2.90	16.86	3.73	11.80
Ferrous oxid (FeO)	6.90	3.22	7.07	3.31	6.84	3.03	5.89	1.53
Manganese oxid (Mn_3O_4)	.36	.19	.50	.43	.92	.06	.68	.08
Lime (CaO)	10.32	.33	8.54	.17	9.57	.22	9.54	.22
Magnesia (MgO)	5.81	.20	6.51	.09	5.61	.11	5.90	.14
Potash (K_2O)	.89	.25	.84	.24	.97	.46	.86	.30
Soda (Na_2O)	2.44	.27	2.64	.31	2.70	.57	2.65	.61
Sulphur trioxid (SO_3)	.20	.78	.61	.49	.51	.74	.53	.70
Phosphorus pentoxid (P_2O_5)	.38	.23	.28	.34	.22	.19	.11	.04
Titanic oxid (TiO_2)	4.07	4.69	4.07	4.84	1.50	2.21	1.50	2.13
Combined water (H_2O)	1.02	16.84	.94	15.61	1.04	18.34	.54	15.06

Samples A, B, E, and F are the unaltered lava, while C, D, G, and H are the adjacent weathered products or soil formed from the respective lava samples. These samples were taken by W. P. Kelley from gulches on Oahu, where large exposed lava bowlders have undergone weathering to such an extent that samples may be taken showing all stages of disintegration from the unaltered lava rock to the soil. The alkalis and silica are the most soluble constituents, and the former are almost entirely leached away in the process of disintegration. The iron is rapidly oxidized to the ferric condition, accompanied by a change to red, yellow, or brown soil, depending on the state of hydration.

SELECTION OF SOIL TYPES.

In selecting soils for this investigation, the policy of selecting all the more important soil types, adopted in previous soil studies in this laboratory, was pursued. The impossibility of drawing conclusions from results obtained from one type of Hawaiian soil has been brought out in previous bulletins of this station. The mechanical and chemical composition of the soils used are given in the following tables:

Mechanical analyses of the soils.

Soil particles.	Soil No. 164.	Soil No. 291.	Soil No. 292.	Soil No. 339.	Soil No. 392.	Soil No. 428.	Soil No. 448.	Soil No. 474.	Soil No. 547.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Clay	21.10	59.35	7.23	19.19	7.87	0.69	6.85	5.24	9.33
Fine silt	51.70	12.13	12.41	22.37	19.36	1.76	20.00	24.20	35.00
Silt	19.50	7.28	8.69	20.42	13.93	5.38	13.45	18.00	30.15
Fine sand	3.79	7.46	22.04	18.13	35.71	15.83	16.31	30.70	10.75
Coarse sand } Fine gravel	.17	.39	18.75	.22	10.22	32.82	8.60	3.43	1.57
Fine gravel		0	20.91	.13	....	13.81	1.94		

Chemical composition of the soils.

Constituents.	Soil No. 164.	Soil No. 291.	Soil No. 292.	Soil No. 339.	Soil No. 392.	Soil No. 428.	Soil No. 448.	Soil No. 474.	Soil No. 547.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Moisture	1.22	9.33	7.65	8.90	5.51	14.94	16.00	13.59	3.12
Insoluble matter	48.11	41.21	38.49	33.75	29.64	34.99	15.10	33.77	34.54
Ferric oxid (Fe_2O_3)	37.47	15.89	16.63	22.69	15.72	8.24	19.20	7.00	30.84
Alumina (Al_2O_3)	3.05	15.39	12.85	11.60	24.78	10.73	16.64	16.79	10.68
Titanic oxid (TiO_2)	1.72	1.25	2.00	2.66	1.80	3.20	4.20	1.80	6.20
Manganese oxid (Mn_3O_4)	.10	.18	.24	.07	2.26	.20	.06	.07	.08
Lime (CaO)	.12	.67	1.84	.39	.52	1.91	.50	3.80	.40
Magnesia (MgO)	1.22	1.41	8.47	.24	.50	2.24	1.80	.85	1.25
Potash (K_2O)	.48	.17	.39	.13	.40	.24	.15	.72	.19
Soda (Na_2O)	1.46	.40	1.36	.40	.21	1.40	.68	.10	.13
Phosphorus pentoxid (P_2O_5)	.07	.20	.57	.26	.28	.22	.29	2.78	.43
Sulphur trioxid (SO_3)	.44	.09	.08	.18	.31	.45	.53	.45	.10
Volatile matter	3.56	12.77	8.42	19.15	19.00	22.24	25.58	20.01	12.20

The above analyses were made by extraction with hydrochloric acid. On fusion with sodium carbonate the analysis of soil No. 164 gave 18.9 per cent titanic oxid.

Soil No. 164 is a peculiar, fine-grained, gray, silty soil, evidently of residual formation. It has an unusually high specific gravity (2.8) and resembles more a mineral deposit than a soil.

Soil No. 291 is very unlike the normal clay soils of the islands. It is brown in color and is very similar in physical properties to the adobe soils of the mainland. Drainage is very poor and plowing difficult, and when the soil dries it becomes almost as hard as cement. It is probably a transported soil, as it occurs in the valleys or gulches extending back into the mountains.

No. 292 is a sandy soil formed from the disintegration and decomposition of volcanic ash. It is highly productive, owing to its excellent physical and chemical composition.

No. 339, a silty soil from windward Oahu, is very productive and is devoted primarily to rice culture.

No. 392 is representative of the types of red silty soils found in the islands.

No. 428, a sandy soil from the Olaa district of Hawaii, has been formed from the disintegration of lava under very humid conditions, and hence is very high in organic matter.

No. 448 represents a yellow clay silt found more or less widely distributed throughout the islands. It contains a notably high content of combined moisture.

No. 474 is a highly organic sandy silt from the Waimea district of Hawaii. It has an extremely loose structure, making it very dusty, but it is highly productive.

No. 547 was chosen as representing the brown clay silts of the islands and as belonging to the class of clays in which the iron content is greater than the alumina. There is another class in which the alumina predominates.

COMPOSITION OF THE SOIL PARTICLES.

Analyses of the soil particles were made by fusion with sodium carbonate. The results are given in the following table:

Composition of the soil particles.

SILICA CONTENT.

Soil particles.	Soil No. 164.	Soil No. 291.	Soil No. 292.	Soil No. 339.	Soil No. 392.	Soil No. 428.	Soil No. 448.	Soil No. 474.	Soil No. 547.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Clay	32.70	47.75	44.25	38.10	32.50	20.35	12.48	34.30	32.10
Fine silt	30.10	42.80	44.75	37.90	28.10	31.70	20.70	42.40	24.80
Silt	1.72	35.50	38.00	34.50	20.60	34.30	16.30	36.50	6.37
Fine sand	2.33	32.50	43.95	31.70	25.60	38.10	19.05	39.40	7.36
Coarse sand	....	29.90	33.25	31.75	22.80	36.15	27.28	33.45	10.92
IRON CONTENT.									
Clay	19.21	15.30	11.53	15.85	16.80	12.86	25.16	10.01	22.35
Fine silt	15.30	18.98	13.36	15.81	16.42	18.05	30.50	9.61	23.70
Silt	45.80	26.60	18.28	20.90	18.90	16.70	31.60	10.56	43.90
Fine sand	39.25	32.15	29.05	30.60	18.92	17.98	24.95	15.96	41.70
Coarse sand	....	23.92	17.10	20.95	18.05	16.60	22.70	14.96	39.10
ALUMINA CONTENT.									
Clay	32.29	27.53	30.86	40.39	42.92	47.95	48.42	30.15	32.40
Fine silt	28.95	26.52	29.51	37.95	39.05	26.68	36.44	29.60	35.22
Silt	13.72	23.93	26.64	34.24	40.91	24.16	34.71	32.50	17.19
Fine sand	30.82	22.48	10.94	26.05	38.93	20.72	41.14	30.02	30.50
Coarse sand	....	33.37	13.60	34.75	49.13	23.87	26.42	27.26	36.41
TITANIUM CONTENT.									
Clay	8.91	3.45	3.16	2.92	2.77	3.62	4.52	2.19	6.31
Fine silt	15.29	4.72	3.31	4.52	3.70	3.89	5.92	2.59	10.19
Silt	26.50	6.40	5.47	7.22	5.79	5.87	7.48	7.41	17.23
Fine sand	21.45	4.38	5.68	8.37	5.48	4.36	7.68	2.21	14.32
Coarse sand	....	2.99	1.79	2.94	3.34	3.35	3.54	3.39	12.01
PHOSPHORIC ACID CONTENT.									
Clay	0.39	0.47	1.70	0.84	0.91	1.32	1.65	4.47	1.24
Fine silt	1.76	1.53	2.22	1.02	2.08	1.58	1.74	4.45	1.64
Silt	.25	.57	.81	.54	.15	.67	.81	1.83	.58
Fine sand	.68	.66	.53	.54	.41	.63	.65	1.51	.38
Coarse sand	....	.95	.61	.61	.38	.38	.56	1.19	.88
MANGANESE CONTENT.									
Clay	0.20	0.54	0.11	0.04	0.34	0.11	0.18	0.46	0.15
Fine silt	.29	.55	.39	.45	2.43	1.08	.31	.53	.33
Silt	.60	1.30	.97	.54	3.18	1.41	.57	.66	.46
Fine sand	.40	.68	.61	.41	5.12	.49	.42	.67	.60
Coarse sand	....	2.60	1.24	1.88	8.75	1.17	.68	.95	4.35
LIME CONTENT.									
Clay	0.72	1.09	1.56	1.11	1.25	2.46	1.32	3.04	1.16
Fine silt	.96	1.73	3.29	.97	1.63	6.43	1.29	6.50	.87
Silt	.30	1.47	.83	.92	1.66	5.90	1.13	6.46	.69
Fine sand	1.04	3.50	1.10	.98	.90	8.28	2.08	6.77	1.02
Coarse sand	....	1.33	4.37	1.79	1.24	7.63	3.05	6.92	2.23

Composition of the soil particles—Continued.

MAGNESIA CONTENT.

Soil particles.	Soil No. 164.	Soil No. 291.	Soil No. 292.	Soil No. 339.	Soil No. 392.	Soil No. 428.	Soil No. 448.	Soil No. 474.	Soil No. 547.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Clay	0.76	0.99	1.18	1.27	0.85	1.67	0.71	1.02	0.92
Fine silt	2.74	2.14	2.73	.96	1.22	5.98	1.49	1.42	1.55
Silt	2.05	1.59	3.27	1.04	.95	4.95	1.21	2.08	2.84
Fine sand	2.65	2.27	2.27	1.26	1.59	9.18	3.44	3.11	3.59
Coarse sand	....	2.35	23.49	3.22	1.57	10.38	15.90	5.13	3.03

Silica.—Generally silica is present in larger amounts in the smaller soil particles. As a general rule, it may be said that it is highest in clay and decreases with an increase in the size of the soil grains. In the above table there are three exceptions to this rule and each of the three samples represents a type geologically of far more recent formation than the other soils. Furthermore, disintegration is by no means complete, and silica being one of the most soluble constituents of lava, it is probable that these soils will increase in silica content as the clay and silt content increases.

Iron.—This element is present in largest amounts in the silt and fine sand particles and in smallest quantities in the clay. The red and brown clay silt loam have the highest iron content. This is one of the most insoluble constituents of the lava, and its concentration in the soil increases on weathering.

Alumina.—Theoretically, aluminum should be found in largest quantities in clay, since pure clay is an aluminum silicate. This holds for only 5 of the 9 types of Hawaiian soil analyzed. The general tendency is toward a relation similar to that existing between silica content and size of soil particle, namely, a decrease in alumina content with an increase in size of particles up to coarse sand. In the sand grains, the alumina content is very high, in several instances being higher than in clay. It is present in largest amounts in the clay silts.

Titanium.—This element, while entirely inert toward plant growth, is of considerable importance in Hawaiian soils. It occurs mainly in silt and fine sand grains and is least prevalent in clay. When present in abnormal quantities, titanium is invariably associated with a high iron content and better soil texture than that of other red clay silts.

Phosphoric acid.—This is present in largest amount in clay and fine silt particles. This fact probably explains the extremely nonavailable condition in which phosphates exist in Hawaiian soils and supports the contention in previous publications of this station that the nonavailable properties of phosphates in local soils are due in large part to the physical influence of the clay, in so far as it governs the concentration and composition of the soil solution.[1]

Manganese.—The manganese content of the grains apparently increases with the size of the soil particles. Only traces of this element are found in clay, while appreciable amounts are present in coarse sand. It may be mentioned in this connection that a soil of high manganese content always possesses a loose, sandy texture, although it may be surrounded on all sides by heavy clay types.

Lime.—While lime is found in appreciable amounts in clay particles, a result to be expected from its general properties, it is present in largest amount in the coarse grains. Lime is an extremely variable constituent in Hawaiian soils, and its presence or absence is influenced to a marked degree by weathering agents.

Magnesia.—Magnesia, being similar to lime in most of its properties, is found distributed in the soil grains with relation to size very much in the same way as lime. Hawaiian soils are almost uniformly higher in magnesia than in lime. Lime is apparently present in larger amounts than magnesia in the clay particles.

PROPERTIES OF THE SOIL PARTICLES.

Coarse sand.—Under this head are classed all particles from 0.2 to 1 millimeter in diameter. It might be expected that these particles would more closely resemble lava in composition, since disintegration has not progressed far, but in most cases leaching has been so complete that there is little difference in composition whether the soil is derived from volcanic ash or lava. Soil No. 291 is a transported type derived from volcanic ash, and the sand grains seem to be composed primarily of a complex magnesium silicate. No. 292 is a soil derived from the same ash but through the action of different weathering agents.

Fine sand.—This division includes all grains ranging in size from 0.04 to 0.2 millimeter in diameter. In passing from coarse to fine sand, the soil particles show a tendency toward an increase in silica, titanium, and iron, and a decrease in alumina. In certain types in which titanium is abundant, silica is present in very small amounts in the coarse particles.

Silt.—The next division consists of particles ranging in size from 0.01 to 0.04 millimeter in diameter. In passing from fine sand to silt there is a further increase in silica content, while the iron and alumina present no uniform change, some samples showing an increase in these constituents, others a decrease.

Fine silt.—These particles vary in size from 0.002 to 0.01 millimeter in diameter. The silica content varies from 20.70 to 44.75 per cent,

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[1] Hawaii Sta. Buls. 35 (1914), 38 (1915), 40 (1915).

the iron from 9.61 to 30.50, and the alumina from 26.52 to 39.05 per cent. As compared with silt and coarser particles, fine silt is higher in silica and alumina and lower in iron.

Clay.—The smallest grains, 0.002 millimeter or less in diameter, in Hawaiian soils are referred to as clay only in so far as this term applies to the size of the soil particles. Grains taken from a red clay soil showed diameters ranging from 0.00165 to 0.00065 millimeter. As regards the composition of Hawaiian clay, silica varies from 12.48 to 47.75 per cent, ferric oxid from 10.01 to 25.16 per cent, and alumina from 27.53 to 48.42 per cent. With the exception of titanium, the other constituents do not vary greatly.

The colors of the clay samples were red, yellow, and brown, the depth of each color varying considerably. The yellow clays were lowest in iron and contained the least combined water. This latter fact does not necessarily hold for yellow soils. The clay separated from soil No. 448, a yellow type, had a red color before ignition. All clays had the same depth of redness after ignition.

The properties of these clays vary as widely as their composition. Soil No. 291, the highest in silica, was as hard and brittle as cement upon drying. The other clays all remained in the form of a fine powder on ignition. The most noticeable of the peculiar properties of these clays is the action toward coagulants. Analyses of the coagulable and noncoagulable grains are submitted herewith. Four samples of soil were treated according to the official method for determining humus. Treatment with ammonium carbonate of the humus extract, which contained large amounts of clay, resulted in a partial coagulation. The results are given in the following table:

Composition of clay coagulated and not coagulated from the humus extract by ammonium carbonate.

Constituents.	Coagulated.				Not coagulated.		
	Soil No. 99.	Soil No. 101.	Soil No. 106.	Soil No. 108.	Soil No. 99.	Soil No. 101.	Soil No. 106.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Silica	29.00	22.24	25.33	23.80	38.21	38.29	46.01
Alumina	37.38	34.93	34.91	37.84	23.40	18.14	21.42
Ferric oxid	33.12	37.33	30.42	31.16	37.39	43.57	32.57

Some Hawaiian clays are almost completely coagulated by ammonium carbonate but it appears that the action of this salt is greatly inhibited in clays high in iron and silica, but low in alumina. The clay in soil No. 108 was entirely coagulated, hence only analysis of coagulated grains is tabulated.

As regards the relation between the composition of the clay and coarser grains, silica and alumina vary between wider limits than in the silts. The clay also contains the highest silica content.

CONCLUSIONS.

(1) There is a wide variation in the composition of soil particles of the same size from different soil types in Hawaii.

(2) This variation is due primarily to the number and intensity of action of the several weathering agents which are instrumental in the disintegration of the lava.

(3) Iron, titanium, and manganese are present in largest amount in the coarse grains. Silica, alumina, and phosphoric acid predominate in the finest particles, lime and magnesia in the coarse grains.

(4) The influence of coagulants upon Hawaiian clays varies with the composition of the clay. Those most difficultly coagulable are higher in iron and silica than those readily coagulable.

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